Selection of Guiding Plate Combined With Surgical Navigation for Microsurgical Mandibular Reconstruction

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Purpose: The present study summarized selection of guiding plate combined with surgical navigation for microsurgical mandibular reconstruction.

Methods: Data from preoperative maxillofacial enhanced computed tomography (CT) scans were imported to ProPlan CMF. The authors performed virtual mandibulectomy and superimposed 3-dimensional (3D) iliac images on mandibular defects. Guiding plates including mandibular fixation device, reconstruction plate, guiding model, and occlusal splint for various mandibular hemimandibular central lateral (HCL) defects were fabricated to fix bilateral residual mandible. The model was scanned, and data were imported into ProPlan CMF and the intraoperative navigation system. Through landmark points upon the guiding plate, position of the residual mandible was determined during surgical navigation. Intraoperative navigation was used to implement the virtual plan. Sagittal, coronal, axial, and 3D reconstruction images displayed by the navigation system were used to accurately determine osteotomy sites and osteotomy trajectory during surgery. Surgical probe guidance was used to mark the osteotomy line and transfer the virtual procedure to real-time surgery. Accuracy was evaluated using chromatographic analysis.

Results: Different guiding plates combined with surgical navigation could be used for various mandibular defects, including mandibular fixation devices for LCL defects, reconstruction plates for LC/L/C defects, and guiding models and occlusal splints for H/L/LC defects (including mandibular ramus). In our study, average and largest shift of the mandible and osteotomy site was <5 mm.

Conclusion: The authors summarized different ways of combining guiding plates with surgical navigation for reconstruction of various mandibular defects, which could improve clinical outcomes of this procedure with high accuracy.

Key Words: Different mandibular defect classification, guiding plate, mandibular reconstruction, surgical navigation

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Extensive reconstruction of mandibular defect is a challenging task in head and neck surgery, which aims to achieve the best possible functional and esthetic outcomes. Application of guiding plates allows manipulation of 3-dimensional (3D) representations of the mandible and donor sites, which can help surgeons plan resection, measure a defect, and plan the harvest and contouring of the fibula flap.[1] However, the errors during preoperative fabrication and use of guiding plates can be accumulated without verification method. Nowadays surgical navigation is used to accomplish accurate reappearance of a surgical plan. Many studies have verified the accuracy of the navigation application on the mid-face region.[2,3] Navigation surgery has rarely been used for mandibular reconstruction because of the mobility of the mandible. Residual mandibular occlusion and mobility can vary for various mandibular defects. According to the hemimandibular central lateral (HCL) classification of mandibular defects by Jewer, central defects that include both canines are designated “C”; lateral segments that do not significantly cross the midline and do not include the condyle are designated “L”; defects of the hemimandible are designated “H”; and other defects include combinations and permutations of the aforementioned ones.[4] Different guiding plates could be used for various classifications of mandibular defects to keep occlusion and residual mandible stable, which could improve the application of surgical navigation for mandibular reconstruction.[5–7] The purpose of the present study was to summarize selection of guiding plates combined with surgical navigation for microsurgical mandibular reconstruction.

METHODS

For all patients in this study, preoperative maxillofacial contrast-enhanced computed tomography (CT) and fibular or iliac noncontrast-enhanced CT scans with 1-mm slice thickness were recorded, and scans were acquired (field of view: 20 cm; pitch, 1.0; slice, 0.75 mm; 120 KV, 280 mA). All tumor resections and mandibular reconstructions were performed by the same chief surgeon (XP). Mandibular defects were classified using the HCL system.[3] Central defects that included both canines were designated “C”; lateral segments that did not significantly cross the midline and did not include the condyle were designated “L”; and lateral segments that included the condyle and did not significantly cross the midline were designated “L” (Fig. 1). This study introduced 4 techniques of guiding plate combined with surgical navigation for 4 various mandibular defects.

LCL Defect: Mandibular Fixation Device

A 57-year-old man suffering from squamous cell carcinoma of the mouth floor involving the lingual cortical mandible presented at our institution. According to preoperative discussion, the treatment plan comprised neoplasm resection, mandibulectomy, bilateral

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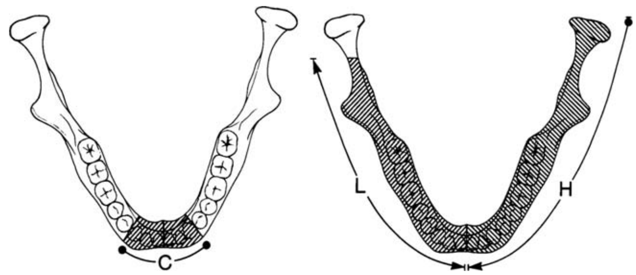

FIGURE 1. Basis of the HCL method for classifying mandibular defects.

neck dissection, and use of free fibula flap for mandibular reconstruction.

Preoperatively, maxillofacial and fibular CT was performed and imported into the ProPlan CMF software (Materialise, Leuven, Belgium) with the Digital Imaging and Communications in Medicine (DICOM) file format. Virtual mandibulectomy was performed by using ProPlan CMF according to margins of the tumors, following which, the 3D fibula image was cut and rotated to be superimposed onto the mandibular defect according to ideal mandible. The position of osteotomy lines and the length of every fibula segment were measured and provided to the surgeon to facilitate intraoperative positioning and placement (Fig. 2). The residual mandible included bilateral mandibular ramus and condyle without any teeth. The mandibular defect for this patient was classified as an LCL defect.

The mandibular fixation device (Cibei, China), which is an Ω-shaped, long titanium plate with a bilateral terminal, is L-shaped with 3 holes. Characteristics of titanium helped ensure that the plate was not only conveniently shaped but also could not get easily deformed during surgery. Bilateral terminals could be bent to conform to the shape of the bilateral mandibular ramus. The metallic character of the mandibular fixation device (thickness 2.0 mm; diameter of screw 2.4 mm) was the same as that of the reconstruction plate.

The mandibular fixation device was placed across the entire defect and was secured to the bone on each side of the resection line. The native bilateral mandibular ramus was used as a template while molding this device. This device was placed far away from the inferior border of the mandibular body and fixed using 3 screws in each mandibular ramus, which could avoid removal of the device before mandibular resection (Fig. 3).

The entire surgical procedure was conducted by the navigation system (iPlan 3.0; Brainlab, Feldkirchen, Germany) according to the virtual plan. Firstly, fixed markers were secured to the patient's calvarium by screws inserted in the scalp. Then an equipment (Z-touch; Brainlab) was used to register the actual maxillofacial skeleton with 3D images on the working station.

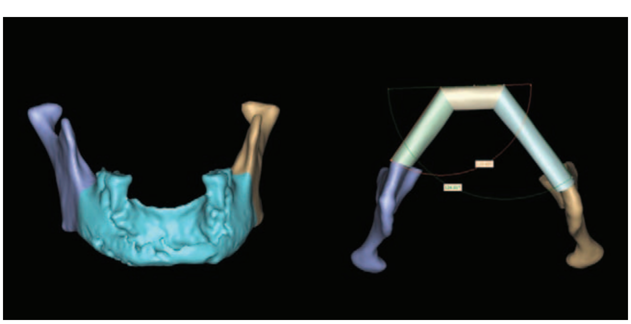

FIGURE 2. Computer planning of mandibular osteotomy and reconstruction with the fibula flap. A: virtual mandibular osteotomy. B: virtual mandibular reconstruction with free fibula flap.

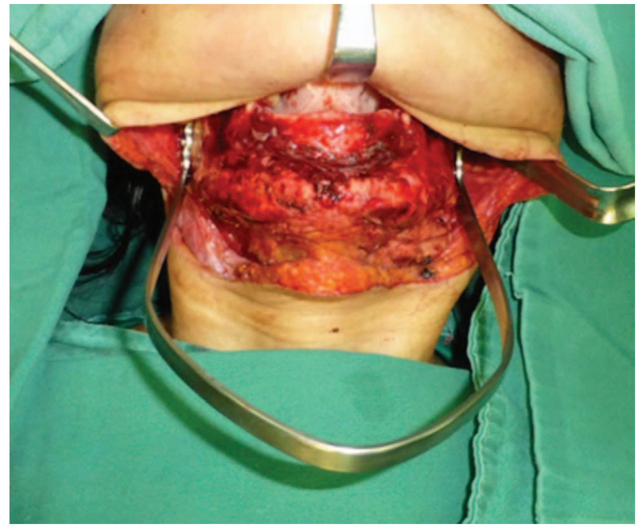

FIGURE 3. The mandibular fixation device was fixed on bilateral mandibular ramus with titanium screws.

The precondition for mandibular navigation surgery was that the mandible and maxilla must have relative stable position throughout the navigation process. This could be accomplished by 2 methods: use an arch bar splint to fix the mandible in centric occlusion; choose 3 distinct anatomical landmarks upon the residual mandible and verify these points with the navigation system to maintain the relative position between mandible and maxilla. These 2 methods were both used in our study. Surgeons used operatively available 2-dimensional images and 3D reconstruction model to accurately mark the osteotomy line (Fig. 4).

After angle-to-angle mandibulectomy, the mandibular fixation device maintained continuity of the remaining mandible. However, because of lack of lower teeth, the previous method used to fix the mandible in centric occlusion was not successful. Therefore, the 2nd method was selected to determine the previous position of the remaining mandible. Positions of bilateral osteotomy lines were used as distinctive anatomical landmarks to register with virtual positions. Owing to the mandibular fixation device, normal

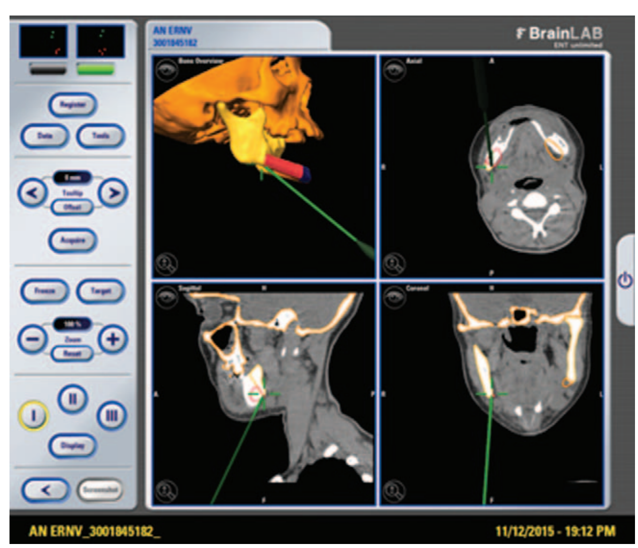

FIGURE 4. Angle-to-angle mandibular defect reconstruction with fibula flap using mandibular fixation device and surgical navigation.

FIGURE 5. A panoramic radiography revealed occupancy lesions of right mandibular body.

mandibular width was maintained. The mandibular fixation device was used as a guiding plate, which could fix the bilateral residual mandible as a whole. With the help of the device and the navigation system, position of the bilateral remaining mandible was determined similar to the previous position before mandibulectomy.

After osteotomy, the shaped fibula flap was placed into the mandibular defect. Positions of the fibula segments were accurately guided and verified by the surgical navigation according to the virtual plan. After fixation between fibula segments and bilateral mandible with miniplates, the mandibular fixation device could be removed.

LC/L/C Defect (not Including Mandibular Ramus): Reconstruction Plate

A female with 23 years old visited our institution, and she complained the visible swelling of the right facial appearance. A panoramic radiography revealed occupancy lesions of right mandibular body (Fig. 5). Virtual mandibulectomy was performed with CAD software (ProPlan CMF; Materialise, Leuven, Belgium) according to the range of tumor, the next step was to superimpose the 3D iliac virtual model on the mandibular defect in its desired orientation according to the ideal mandibular contour (Fig. 6). Once the tumor destroyed the contour of the mandible, mirroring function was used to recover the ideal mandibular contour. The relevant parameters about every iliac segment were used for the surgeon to accomplish intraoperative harvesting and placement. The residual mandible included the hemimandible and unilateral mandibular ramus and condyle. This mandibular defect was classified as an LC defect.

After the virtual plan, a neomandible stereomodel consisting of the residual mandible and iliac segments was manufactured with 3D printers. A reconstruction plate was prebent according to the contour of the ideal mandible and fixed upon the reconstructed mandibular model with screws, which was used as a guiding plate (Fig. 7). Then the reconstruction plate and the fabricated

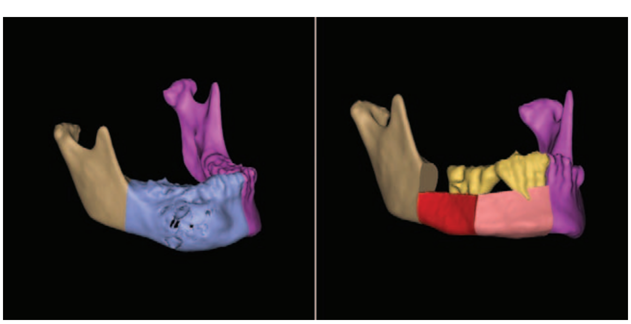

FIGURE 6. Virtual plan of mandibular osteotomy and reconstruction with vascularized iliac crest flap on Surgicase workstation. A: virtual mandibular osteotomy. B: virtual mandibular reconstruction with vascularized iliac crest flap.

FIGURE 7. Fabrication of reconstructed mandibular stereomodel and prebent reconstruction plate. The reconstruction plate fixed on the reconstructed mandibular model using 2 titanium screws. A: reconstructed mandibular stereomodel. B: prebent reconstruction plate. C: the reconstruction plate fixed on the stereomodel.

mandibular model were scanned by the 3D scanner, data about the reconstruction plate were saved in the STL format and imported to the Brainlab software (BrainLab Inc, Feldkirchen, Germany). Six points indicating the position of the titanium screws were marked to adjust the position of the residual mandible (Fig. 8).

During the surgery, the first step was to use an arch bar splint to fix the mandible in centric occlusion. After the registration of the navigation system, the virtual osteotomy was transferred to real-time surgery. After osteotomy, residual teeth were fixed by the same arch bar splint, which could determine the position of the unilateral residual mandible. Usually, there were not enough teeth to maintain the stable occlusion on the other side, so the position of the residual mandible on this side could not be determined by the arch bar splint. The reconstruction plate was fixed on the bilateral remaining mandible according to the 6 marked points, indicating position of the titanium screws, which could maintain the previous position of the residual mandibular ramus (Fig. 9). The vascularized iliac was harvested and shaped according to virtual plan and positioned with navigation system.

H/L/LC Defect (Including Mandibular Ramus): Guiding Model and Occlusal Splint

Patient 1: Guiding Model

A 38-year-old female presented at our institution with visible right-sided facial deformity. Mandibulectomy without reconstruction

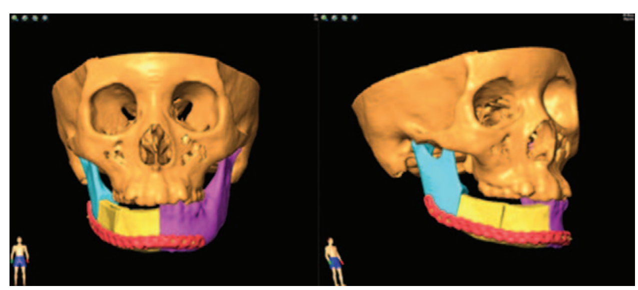

FIGURE 8. Navigation registration of the neomandible with the reconstruction plate. Six points on the 2 sides of the reconstruction plate are marked. A: frontal view of the neomandible. B: lateral view of the neomandible.

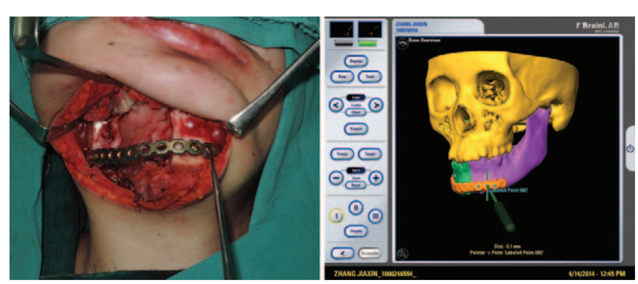

FIGURE 9. Fixation of reconstruction plate on the residual mandible according to the 6 marked points indicating positions of titanium screws. A: the navigation probe is positioned on the titanium screw. B: corresponding location of the titanium screw in the navigation system.

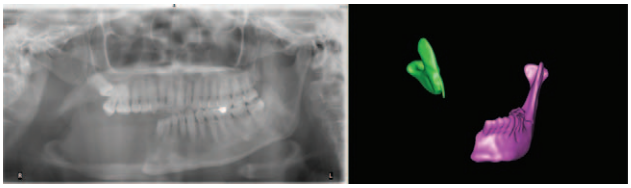

FIGURE 10. Preoperative panoramic radiograph and 3-dimensional imaging show a mandibular defect involving the right mandibular body and ramus. A: preoperative panoramic radiograph. B: 3-dimensional imaging of the residual mandible.

was performed for ameloblastoma 2 years ago. Panoramic radiography and 3D imaging revealed a unilateral mandibular defect including the right mandibular body and ramus (Fig. 10). The mandibular defect for this patient was classified as an LC defect. The patient complained about deviant jaw opening and poor occlusion because of the mandibular defect. Ideal occlusion could be reproduced through the doctor's thrust toward the residual mandible.

Preoperative maxillofacial contrast-enhanced CT and fibular noncontrast-enhanced CT scans were acquired. Before surgery, the virtual plan was finished to supply the position of the osteotomy lines and the length of every fibula segment. A guiding model was designed to fix the residual mandible and condyle (Fig. 11). Two points were registered in the navigation system to adjust position of the guiding model. On the contrary, the path of condylar insertion was designed to stabilize the position of the condyle.

During surgery, an arch bar splint was used to reproduce ideal occlusion. With surgical navigation, osteotomy was accomplished. The guiding plate was used to fix the residual mandible and condyle, which allowed the mandible to move as a whole. Through navigation verification of these screws on the guiding plate, the relative position between the whole mandible and maxilla was stable. The fibula was shaped according to CAD and recorrected using surgical navigation (Fig. 12).

FIGURE 11. Fabrication of the guiding plate.

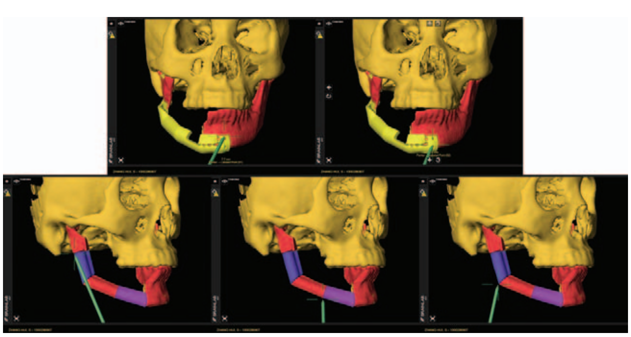

FIGURE 12. Virtual plan of mandibular osteotomy and reconstruction with the fibula flap in ProPlan CMF software. A and B: virtual plan of mandibular osteotomy and cutting guide. C, D and E: virtual plan of mandibular reconstruction with free fibula flap.

FIGURE 13. Preoperative panoramic radiograph and 3-dimensional imaging show a mandibular defect involving the left mandibular body and ramus. A: preoperative panoramic radiograph. B: 3-dimensional imaging of mandibular defect.

Patient 2: Occlusal Splint

A 53-year-old man presented at our institution with visible left-sided facial deformity. He had undergone mandibulectomy without reconstruction, followed by radiation therapy (70 Gy), for squamous cell carcinoma of the tongue 6 years ago. Panoramic radiography and 3D imaging showed a unilateral mandibular defect including the right mandible (Fig. 13). Furthermore, the patient complained of limited mouth opening and poor occlusion because of soft-tissue contracture and the mandibular defect. It was challenging to improve the poor occlusion preoperatively only with thrust toward the residual mandible. The mandibular defect for this patient was classified as an L defect.

Maxillary and mandibular stone models of the patient were fabricated, and ideal occlusal relationship was determined by a prosthodontist on an articulator. An occlusal splint was fabricated to fix the ideal occlusal relationship (Fig. 14). Stone models fixed by the occlusal splint were scanned using a 3D optical measuring system (Smart Toptics), and STL data were acquired. The occlusal splint and mandibular and maxillary stone models were imported into the Geomagic Studio 7 software (Raindrop Geomegic, Durham, NC). The registration function was used to determine the ideal mandibular position in the software, which could help complete the virtual plan.

By using the ProPlan CMF software, osteotomy lines were marked for the mandible moved into the stable position. The ideal mandibular contour was formed by the mirroring tools. According to ideal mandibular contour, we superimposed the 3D fibular image

FIGURE 14. Occlusal reconstruction with occlusal splint. A: frontal view of occlusal splint. B: the other side of occlusal splint. C: the occlusal splint is used to confirm the position of the upper and lower teeth.

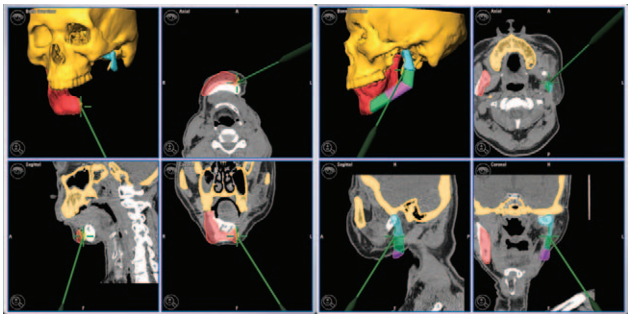

FIGURE 15. Osteotomy line and position of the fibular segment are verified using surgical navigation. A: the osteotomy line is verified using surgical navigation. B: the position of the fibular segment is verified using surgical navigation.

on the mandibular defect in its desired orientation. The position of osteotomy lines and relevant parameters regarding the shape of the free fibular flap were provided to the surgeon (Fig. 15). In addition, the position of osteotomy lines and relevant parameters regarding the shape of the free fibular flap were provided to the surgeon.

During surgical navigation, an occlusal splint was used as a guiding plate to maintain the relevant position between mandible and maxilla throughout the navigation process. Under the guidance of a surgical probe, the virtual plan was transferred to real-time surgery.

Postoperative nonenhanced CT was obtained 1 month after surgery to evaluate outcomes of mandibular reconstruction with guiding plate and navigation surgery. The difference between postoperative and planned configuration of the mandible was evaluated by chromatography (Geomagic, Morrisville, NC) (Fig. 16).

The flow diagram in Figure 17 shows selection of guiding plate combined with surgical navigation for microsurgical mandibular reconstruction.

The ethical approval was given for our study. The ethical approval document number is PKUSSIRB-201522051. This study features human subject, and we confirm that we have read the Helsinki Declaration and have followed the guidelines in this investigation.

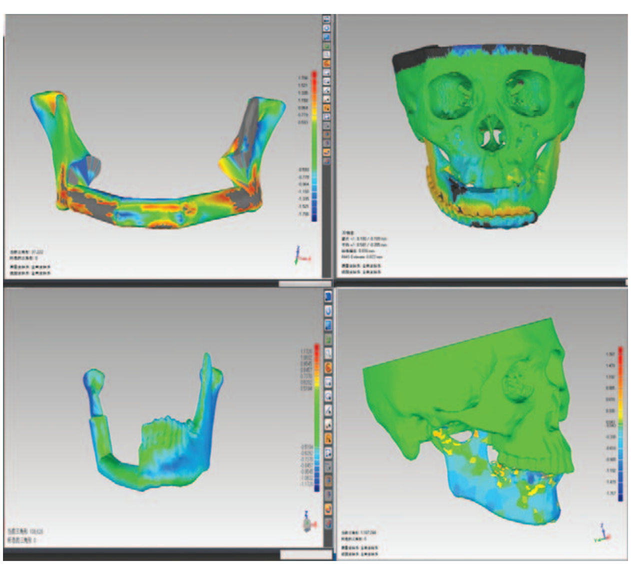

FIGURE 16. Chromatographic analysis between every segment of the reconstructed mandible before and after surgery. A: chromatographic analysis for LCL mandibular reconstruction with fibular flap. B: chromatographic analysis for C mandibular reconstruction with iliac crest flap. C: chromatographic analysis for LC mandibular reconstruction with fibular flap. D:chromatographic analysis for the unaffected side of mandible.

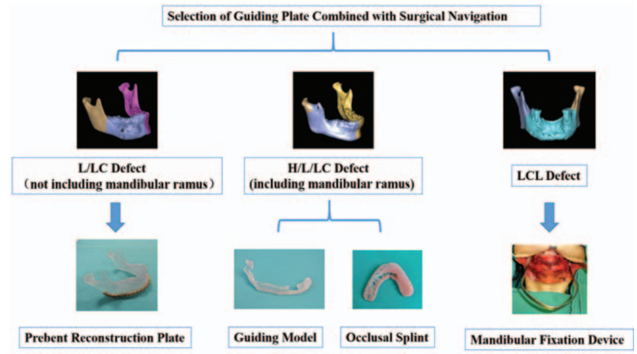

FIGURE 17. A flow diagram for selection of guiding plate combined with surgical navigation for microsurgical mandibular reconstruction.

RESULTS

The average operation time for the aforementioned 4 patients was 370 minutes. The vascularized flap survived with no complication. With patients' approval, additional cost of the entire process was added to 6800RMB (approximately 1025 USD), and the time we spent preparing this surgery was 2 days more than that required for traditional surgery because of virtual planning, fabrication of the guiding plate, and surgical navigation. The fabricated model including the neomandible and guiding plate costed 4000RMB (approximately 600 USD), and the navigation system used during surgery costed 2800RMB (approximately 425 USD).

Favorable cosmetic results were obtained with the guiding plate and surgical navigation according to our clinical examination. By using our method, we precisely recovered the original configuration of the mandible. Bilateral condyles were located in the temporomandibular joint fossa. For these 4 patients, the average shift compared with the preoperative ideal position was 0.357 ± 0.239 mm. The average largest shift was 2.275 ± 1.212 mm. The shift of the osteotomy site was 2.017 ± 0.910 mm (Supplementary Digital Content, Table 1, http://links.lww.com/SCS/B209).

DISCUSSION

Results of the present study indicate that different guiding plates could be combined with surgical navigation for reconstruction of various mandibular defects. A mandibular fixation device was used for LCL mandibular defects. A prebent reconstruction plate was regarded as the guiding plate for LC/L/C mandibular defects that did not include the mandibular ramus. On the contrary, a guiding model was preoperatively fabricated for H/L/LC mandibular defects that included the mandibular ramus, and if occlusion was difficult to restore during surgery, occlusal splints were also preoperatively fabricated as guiding plates. Accuracy evaluation revealed that guiding plate with surgical navigation can improve the appearance outcome with high accuracy.

In terms of combining a guiding plate with surgical navigation, there are 2 basic elements. Ability to fix the bilateral residual mandible as a whole: Because the range of the residual mandible can differ, an occlusal splint, reconstruction plate, mandibular fixation device, and guiding model could have similar effects. Soft-tissue contracture and bone tissue instability for secondary mandibular reconstruction or soft-tissue growth of a tumor could be responsible for instability of preoperative occlusion. A mobile mandible would influence application of digital surgery and accurate placement of fibular or iliac segments. Occlusal splints were used as guiding plates to reconstruct occlusion and to maintain upper and lower jaws in their relative positions. For certain mandibular defects such as LC/L/C mandibular defects, the unilateral residual mandible did not include enough teeth to determine the position. In such patients, prebent reconstruction plates could connect bilateral resident mandibles. Through unilateral occlusion, position of bilateral resident mandibles was accurately located. For larger mandibular defects such as LCL mandibular defects, no teeth could be used for occlusal reconstruction, and the shape of the reconstruction plate was unsuitable to the bilateral mandibular ramus. The mandibular fixation device was invented as a guiding plate to re-establish the relative relationship between bilateral mandibles. For L/LC/H mandibular defects, the space used to fix the reconstruction plate or mandibular fixation device was not adequate enough. Fitness between the residual condyle and the guiding model could be used to stabilize the movable condyle. There are certain landmark points on the guiding plate, which could be used for surgical navigation to adjust and verify the position of the entire mandible. Certain points indicating the position of the titanium screws upon the occlusal splint, the reconstruction plate, and the mandibular fixation device were marked in the navigation system.

Our method has several advantages. First, it is the first to summarize different methods of using guiding plates and surgical navigation for classification of different mandibular defects. Second, it could solve the placement of the residual mandible without enough teeth, which could not need other fixation equipment, thus decreasing the cost of surgery.

The CAD allows virtual manipulation of 3D representations of the mandible and donor site, which can help surgeons plan resection, measure the defect, and plan harvest and contouring of fibular flaps.[8,9] At present, CAD/CAM technology is widely used for mandibular reconstruction with free fibular flaps.[10,11] This technology offers guiding plate for the fibula harvesting and mandibular reconstruction, which can improve the accuracy of microsurgical mandibular reconstruction. However, these technologies still have certain shortcomings. The more space for positioning the guide results in more operative time and more invasive treatment. The soft tissue around the mandible and fibula can influence the stability of the guiding plate, which may result in positional variation. Schepers et al reported that the primary error of CAD and CAM probably resulted from incorrect positioning of the guiding plate, caused by overriding of soft tissues underneath the guide in the mental region.[12] The errors are accumulated during the virtual plan and fabrication of the guiding plate without verification method.

The computer navigation technique provides real-time feedback and can be augmented during maxillofacial surgeries.[13] Previously, navigation surgery was rarely used for mandibular reconstruction because of mandibular mobility. There are 3 possible solutions to keep mandible stable.[14] The first method is to place the patient in intermaxillary fixation during CT and surgery although it is not feasible for surgeries employing an intraoral approach. The Second approach is to place the mandible in centric relation or centric occlusion, either manually or using a dental splint. Although mandibular movements are convenient for surgery, they undermine the accuracy of intraoperative navigation. In our study, this solution was used to overcome mandibular mobility. Before the osteotomy, the mandible was placed in centric occlusion by an arch bar splint. If tumor resection changed the occlusion, the occlusal splint for ideal occlusion would be fabricated preoperatively. A 3rd approach is to use a special sensor frame fixed on the mandible which could allow surgeons to track the jaw position without increasing navigation errors. These 3 methods provide an opportunity to improve accuracy of mandibular navigation.[3]

Some studies about the application of computer-aided navigation for mandibular reconstruction had been done with some success. For example, in 2008, Casap et al compared 2 navigation systems for mandibular reconstruction.[14] The navigation error for these 2 systems was <0.5 and 3 to 4 mm. In 2017, Bernstein et al completed 224 unnavigated and 224 3D-navigated osteotomies on anatomical models, through which they found the distance, pitch, and roll for navigated mandibular and maxillary osteotomies were 2 mm and 3° in most patients.[15] However, these studies focused on position of a point or osteotomy line in a model or corpse.[16] In our study, the average shift of the neomandible and osteotomy site was <5 mm; hence, verification between the guiding plate and surgical navigation could guarantee reconstruction of various mandibular defects with high accuracy.

CONCLUSION

We summarized different methods of combining guiding plates with surgical navigation for reconstruction of various mandibular defects, which could improve clinical outcomes of this procedure with high accuracy.

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